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# Fractures in the horse:

# - Epidemiology of fractures: the role of kick injuries in equine fractures

# - Metal plate removal after osteosynthesis in horses: a retrospective study

**Inaugural-Dissertation**

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# 1. Zusammenfassung

Frakturen sind häufig bei Pferden, können Komplikationen entwickeln und haben eine vorsichtige bis schlechte Prognose. Der erste Teil der Dissertation stellt eine retrospektive Studie über die Epidemiologie der Frakturen dar. Die vielen vorhandenen Studien fokussieren fast ausschliesslich auf die Rennpferde. Unsere Hypothese war, dass Frakturen nach Hufschlägen in einer gemischten Population häufig sind und eine schlechte Prognose besitzen. Wir untersuchten Krankengeschichten von Frakturpatienten, welche zwischen 1990-2015 an der Pferdeklinik der UZH vorgestellt wurden. Hauptursache waren Schlagverletzungen. Der betroffene Knochen, das Alter des Pferdes, der Grad der Lahmheit und die Fraktur-Konfiguration beeinflussen die Prognose. Unsere Erkenntnisse helfen Besitzern, Risiken zu vermeiden und Tierärzten bei der Beratung der Besitzer hinsichtlich Therapie oder Euthanasie. Der zweite Teil fokussiert auf die Implantatentfernung (IE). Die routinemässige Durchführung der IE wird in der Humanmedizin kontrovers diskutiert. Krankengeschichten von Patienten nach IE, welche zwischen 1990-2015 an der Pferdeklinik der UZH vorgestellt wurden, wurden auf Signalement, Anamnese, Frakturtyp, Indikation, Zeitraum, Erfolg und Komplikationen untersucht. Die meisten Implantate wurden von der Ulna, der Mandibula und den Röhrbeinen entfernt. Hauptindikationen waren Infektion, Lahmheit und Fohlen im Wachstum. Die Erfolgsrate war mit 85.1% sehr hoch, jedoch können Infektionen und Refrakturen eintreten. IE in symptomlosen Patienten wird nicht empfohlen, ist aber indiziert bei Fohlen im Wachstum und bei symptomatischen Patienten.

Stichworte: Pferd, Fraktur, Schlagverletzung, Implantatentfernung, Refraktur

## 2. Summary

Fractures are common in horses and its treatment is associated with complications and poor outcome. The first part of this thesis is a retrospective study of the epidemiology. Similar studies in racehorses revealed that age, bodyweight, degree of comminution, contamination and first aid affect outcome. Our hypothesis is that fractures due to kicking injuries are common and have poor prognosis. We reviewed records of fracture patients between 1990-2015 at the Equine Hospital of the University of Zurich. The main causes of fracture in non-racehorse were kicks. Affected bone, age of the horse, degree of lameness and fracture configuration significantly determine outcome. Findings help owners to avoid exposure of horses to risks as well as veterinarians in advising owners to opt for treatment versus euthanasia. The second part of this study focuses on implant removal (IR). IR is widely debated in human medicine. Medical records of horses, which underwent IR at our institution between 1990-2015 were reviewed. Signalment, history, fracture type, indication, timespan, complications and outcome were recorded. Most plates were removed from ulnae, mandibulae and cannon bones. Common indications were infection, lameness and young age. IR was successful in 85.1% of the patients. Common complications were persistence of infection and refracture, which had infaust prognosis. IR in asymptomatic mature patients is not advocated but is justified in foals and symptomatic patients. Good results can be expected but severe complications may occur.

Keywords: horse, fracture, kicks, implant-removal, refracture

## 3. Introduction

Fracture in the equine patient is a very common diagnosis in our hospital. Five to 6% of the horses presented to the Equine Department, Vetsuisse Faculty, University of Zurich are diagnosed with a fracture. Together with joint diseases, colics, and teeth problems, it is a common cause of death in equids. Many studies can be found on the occurrence of equine fractures, but most concentrate on racehorses [1-4]. These studies are not representative for the mixed swiss equine population, being that the racing industry is of rather small relevance in Switzerland [5]. There obviously are different types of fractures and different types of patients; some are easier to manage than others and may have a more or less favourable prognosis. In either case, the patient will have to be paused during treatment and reconvalescence for rehabilitation and training. This process of healing could last from just some weeks of rest to many months of training, or result in the end of the athletic career. Horses need to be able to bear weight on all limbs and the experience shows that they do not tolerate immobilization well, show slower bone healing compared to other species and are prone to infections. These are all factors that make fractures a feared diagnosis. Fractures of long weight bearing bones, such as humerus, radius, femur, tibia and third metacarpal/metatarsal bone are particularly feared because of the difficulties in treatment, related complications, costs and low survival rates. Regarding configuration there is a consistent difference whether the fracture is incomplete and only involves one cortex (fissure), simple and complete affecting both cortices, or comminuted; the latter being the most difficult to treat and the one with the worst prognosis. Open fractures are by definition contaminated and thus predisposed for developing infection. Heavy horses can develop life-threatening laminitis on the contralateral limb as a result of excess weight bearing if they cannot support enough on the fractured limb [6]. Weight also plays a role in making the fracture more likely to dislocate and consequently more difficult to reduce and to fix. The understanding of the epidemiology of fractures in the equine patient helps to detect risk factors, to minimize the exposure of horses to these risks, to identify factors affecting outcome and to be able to correctly advise owners when making the decision of treating the horse versus euthanasia. In the first part we therefore retrospectively collected information on fracture patients over two decades to get an overview of the epidemiology of fractures and of their outcome. Our purposes were to determine main causes of fractures in the Swiss horse population and risk factors affecting survival of fracture patients. We hypothesized that kick injuries would be the main cause of fractures and that fractures after kicks would be associated with a significantly lower positive outcome rate compared to fractures after other causes.

The second part of this work focuses on the aftercare of patients, which underwent open reduction and internal fixation of the fracture and later had their plate(s) removed. Osteosynthesis is the best way to achieve anatomic reduction and stable fixation, which are prerequisites for early return to function [7]. In many cases, it is even cheaper and related to fewer complications than conservative treatment with a cast [8]. However, metal implants are sometimes the origin of complications such as infection or lameness [9]. In many of these cases the only possibility to resolve these symptoms is to remove the plate. In human medicine the topic of implant removal after fracture healing has been extensively discussed, in particular because of the trend to routinely remove implants even if asymptomatic [10-13]. Current opinion in human medicine seems to be that metal implants which do not cause problems can be left in situ, but in practice many surgeons still report to routinely remove implants [14; 15]. Implants in the growing skeleton represent a special case, as they are routinely removed to avoid disturbing consequences to growth. The intervention does not guarantee relief from symptoms and must not be taken slightly; complications do occur and can be very serious [16; 17]. There is very little literature on the topic in equine surgery, and surgeons must rely on their experience when choosing the approach to a horse with symptoms attributable to metal plates [18; 19]. For this purpose clinical records of horses, which had plates removed after fracture fixation between 1990 and 2015 were reviewed. The aim of this part was to describe plate removal interventions carried out in our clinic, focusing on indications, timing and complications.

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# 4. Part I: Epidemiology of fractures: the role of kick injuries in equine fractures

## 4.1 Introduction

Equine fractures are common and affect horses of all ages and breeds.[1] At the Equine Department, Vetsuisse Faculty, University of Zurich, approximately 5% of the patient population are diagnosed with a fracture. Published studies on the epidemiology of fractures focus on racehorsefractures occurring during training or racing,[2-5] many of which are stress or fatigue fractures affecting various bones.[6-9] These fractures have been studied extensively and are thought to be caused by repetitive stress over short intervals, which prevents repair of bone microdamage attributable to heavy strain.[10,11] A literature review found that the typical characteristics of stress fractures include a high degree of morphologic consistency, evidence of long-standing lesions at the fracture margins, the possible presence of a pre-existing incomplete fracture and no association with a specific trauma.[12] The Swiss Centre for Agricultural Research (AGROSCOPE), which is affiliated with the Federal Office for Agriculture (FOAG), introduced a new system for the mandatory registration of equids in Switzerland. Their published report showed that in 2013, 53% of equids were females and 81% were older than 3 years, and of approximately 150 breeds, 40% were warmbloods. Not only was it apparent that the majority were not racehorses, it also showed that the horses were mainly used for pleasure, jumping, dressage, driving, vaulting and endurance, and only 9% were raced.[13]

Kicks from other horses have been shown to be an important cause of fractures in a mixed-breed horse population; in one retrospective study, 121 of 256 (47.2%) kicks from horses were associated with a fracture and in 17 of these cases (14.1%), the horse had to be euthanized.[14] The force of a kick from a single hoof can be as high as 1 ton, and steel horseshoes produce even higher peak forces, thus posing a greater risk of serious injury (Fig 1).[15,16]

Fig 1: Fractures caused by a kick are common in a mixed-breed population of equids. Often they affect bones with little soft tissue coverage, are open and comminuted, especially if the horse delivering the kick is shod.

Efforts to improve the conditions in which horses are kept include group housing to meet their social needs.[17] However, poorly established hierarchical relationships among horses and lack of social skills can result in conflict and thus kick injuries, especially in groups that share resources such as food, water or space and lack a dominance hierarchy.[18] The need for adequate management and preventive measures to prevent kick injuries in herds has been discussed.[19,20]

The prognosis and outcome of fractures in horses hinge on several factors and can vary greatly depending on which bone is affected. Old age, increased body weight and fractures with marked comminution and contamination are usually assumed to be associated with a poor outcome. The results of studies on prognosis and outcome that have been done in racehorses cannot be directly applied to the mixed-breed population of horses in Switzerland. The goal of the present study was to investigate epidemiological factors of fractures in a large mixed-breed horse population and to determine (1) the main causes and (2) the risk factors affecting outcome. We hypothesised that kicks from horses are the main cause of fractures and that fractures caused by kicks have a poorer outcome than fractures caused by other injuries.

## 4.2 Materials and methods

Patient histories at the Equine Department, Vetsuisse Faculty, University of Zurich, are saved in a FileMaker Pro 2.0 Database. The records of horses (including donkeys and mules) presented from January 1992 to September 2014 were searched for the keywords “fracture” and “fissure”. Fractures of the skull, vertebrae, ribs, scapula, pelvis, long weight-bearing bones (humerus, radius, femur, tibia, and third metacarpal/metatarsal bones), ulna, second and fourth metacarpal and metatarsal bones, phalanges, and sesamoid bones were included in the study. Osteochondral fragmentation, separate ossification centres and other fragments not clearly attributable to a fracture, as well as tooth fractures, were not included. In horses that were presented with multiple fractures, only the most severe fracture was included, and in horses presented multiple times for different fractures, each fracture was considered separately. Data on signalment, history, clinical findings, results of diagnostic imaging, characteristics of the fracture, therapy and short-term outcome were collected. Signalment included age (<3 years, 3-14 years, and ≥15 years), sex, breed (donkeys and mules where treated as breeds in this study), weight (<100, 100-199, 200-299, 300-399, 400-499, 500-600, and >600 kg) and use (athlete or pleasure). Fractures were classified as acute when the animal was presented within 2 days of fracture occurrence, and subacute when presented 3 or more days after fracture occurrence. The causes of fractures were categorised as a kick from another horse, collision with a stationary object such as a wall or a tree, stress injury, fall and road traffic accident (fracture occurred with the horse standing in the trailer or on the road). The location of the horse at the time of the fracture was classified as pasture, individual box stall or small paddock, arena or racetrack while being ridden/driven, outdoors while being ridden/driven, permanent group housing, horse trailer, during handling (such as walking the horse or while grooming) or in hospital during recovery from general anaesthesia. The only locations where there was no contact with other horses were the individual box stall, small paddock and the hospital during recovery from general anaesthesia; in all other locations the horses may have had contact with other horses. The presence of a skin wound (open/closed fracture) and severity of the lameness at admission (grade 0-5, AAEP) were noted. The fracture configuration was retrieved from reports by board-certified radiologists and divided into 5 types: fissure fracture, simple fracture, comminuted fracture, impression fracture and Salter-Harris fracture. A fissure fracture was defined as a crack extending from the surface into, but not through, the bone. Simple fractures had only one fracture plane comminuted fractures had multiple fragments and impression fractures had an area of the cortex displaced beneath the bone surface. Fractures involving the growth plate in young horses were regarded as Salter-Harris-type fractures. Treatment was divided into osteosynthesis (with plates or screws), other invasive therapies requiring general anaesthesia (arthroscopy, cerclage wire, removal of fragments/sequestra), and conservative management or other invasive treatment without general anaesthesia (casts, bandages, slings, local wound treatment, drugs). The outcome was considered successful when the animal was discharged from the hospital sound or with a fair to good prognosis, and unsuccessful when the animal was discharged with a guarded prognosis or was euthanased at admission or because of complications. Data editing was done using Excel (Microsoft Inc.), and the statistical analyses were done using Stata Software (StataCorp., 2011; Stata Statistical Software: Release 12; College Station, TX, USA: StataCorp LP). Frequencies of variables related to history, clinical findings, therapy and outcome were calculated. Associations between variables were determined using the chi-square test; Fisher's exact test was used when one of cells contained $n \leq 5$. For statistical analysis, only known variables were compared. Differences were considered significant at $P \leq 0.05$. Finally, a step-wise logistic regression was carried out and significant variables affecting outcome were identified. Variables were entered if the P-value was $< 0.2$ and the step back procedure was stopped when all variables were $\leq 0.05$. Of particular interest for this study was the analysis of associations involving cause of fractures and outcome, especially in relation to kick injuries.

## 4.3 Results

### 4.3.1 Descriptive statistics

*Population*

A total of 1,845 horses with fractures fit the inclusion criteria for the study. Mean age of the affected horses was 9.99 years (range 1 day-36 years) and there were 254 young (<3 years), 1,204 adult (3-14 years) and 387 aged horses (≥15 years). There were 834 (45.3%) geldings, 780 (42.3%) mares and 230 (12.5%) stallions; the sex had not been recorded in one case. Breed distribution was 964 (52.3%) Warmblood horses (mostly Swiss and German Warmbloods), 245 (13.3%) Thoroughbred/Standardbred horses, 116 (6.3%) Freiberger/Haflinger horses, 109 (5.9%) Icelandic horses, 106 (5.8%) ponies, 80 (4.3%) Quarter horses, 63 (3.4%) Arabian horses, 20 (1.1%) donkeys, 18 (1.0%) Friesian horses, 9 (0.5%) draft horses, 1 mule and 114 (6.2%) mixed-breed or other breeds of horses. The median weight was 500 to 600 kg, and weight distribution showed that 2.4% of horses were lighter than 100 kg, 4.3% were between 100 and 199 kg, 4.4% between 200 and 299 kg, 12.3% between 300 and 399 kg, 22.49% between 400 and 499 kg, 46.7% between 500 and 600 kg and 7.3% were heavier than 600 kg. There were 528 (28.6%) competition horses.

*History*

Acute fractures occurred in 922 (51.7%) horses and subacute fractures in the remaining 863 (48.4%). The causes of fractures included a kick from another horse in 499 cases (27.1% of all cases and 43.6% of known causes), a fall in 252 (13.7% of all cases and 22.0% of known causes), collision with a stationary object in 231 (12.5% of all cases and 20.2% of known causes), stress related to training or competition in 116 (6.3% of all cases and 10.1% of known causes) and a road traffic accident in 46 (2.5% of all cases and 4.0% of known causes). The cause of the fracture was unknown or not recorded in 701 (38.0%) cases (Fig 2).

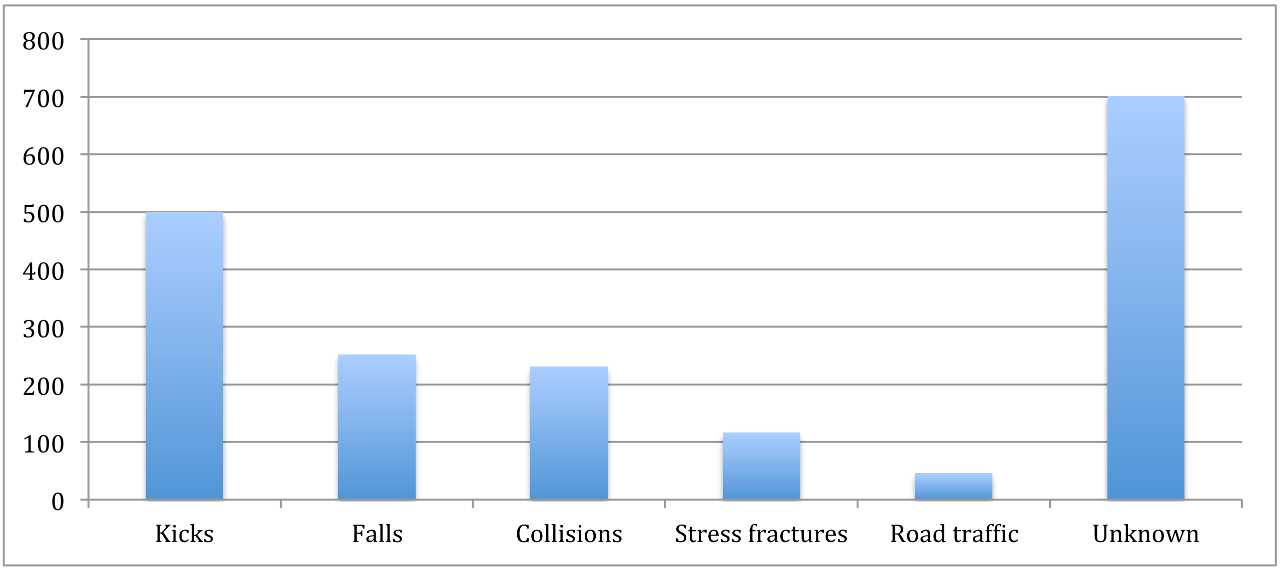


Fig 2: Distribution of causes of fractures in a mixed-breed hospital population of 1845 equids from 1992 - 2014.

Fractures were sustained while on pasture in 472 (25.6%) cases, alone in a box stall or small paddock in 159 (8.6%), outdoors while being ridden/driven in 157 (8.5%), in permanent group housing in 135 (7.3%), on a racetrack or in an arena in 130 (7.1%), during handling in 116 (6.3%), in a horse trailer in 22 (1.2%) and during recovery from general anaesthesia in 4 (0.2%) (Fig 3).

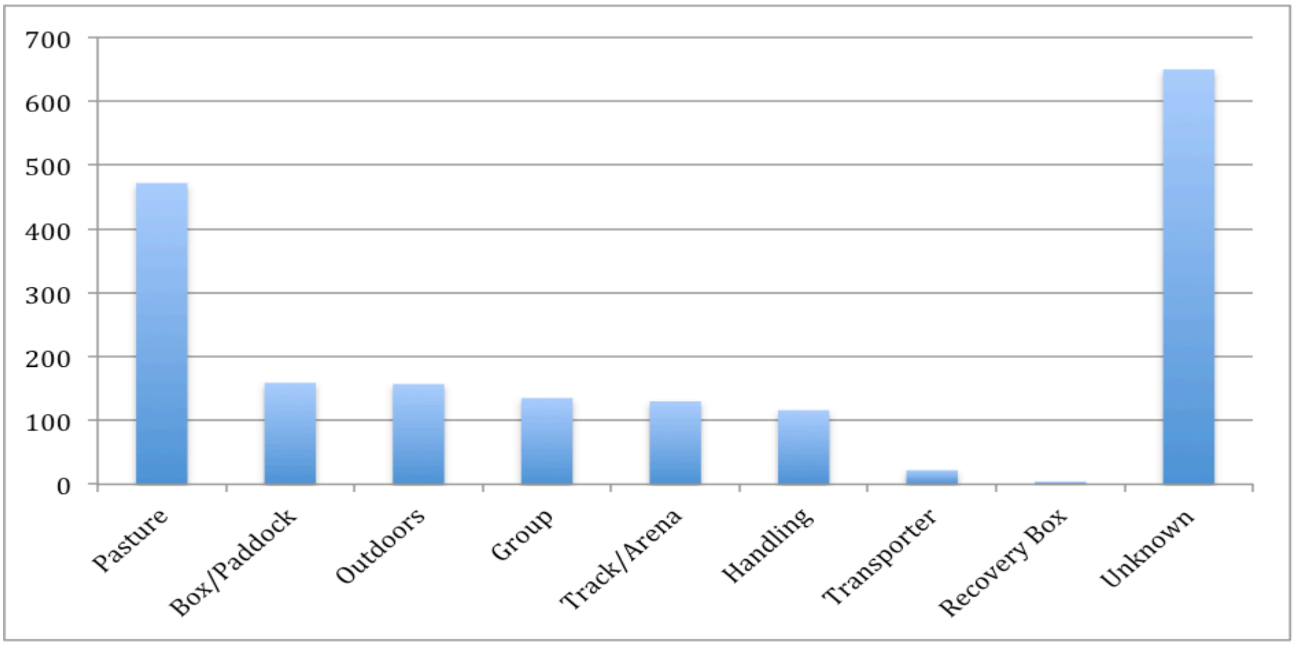


Fig 3: Distribution of environmental locations where 1845 fractures occurred.

*Clinical findings*

Fractures of the second and fourth metacarpal and metatarsal bones were most common (n=282), followed by bones of the skull (n=273), first phalanx (n= 193), third phalanx (n=178), pelvis (n=138) and tibia (n=111). Less commonly fractured bones were the radius (n=96), ulna (n=95), third metacarpal and metatarsal bones (91), proximal sesamoid bones (n=61), vertebrae (n=49), humerus (n=43), distal sesamoid bone (n=40), small bones of the tarsus (n=39), femur (n=36), small bones of the carpus (n=35), middle phalanx (n=31), patella (n=24), scapula (n=21) and ribs (n=9) (Fig 4).

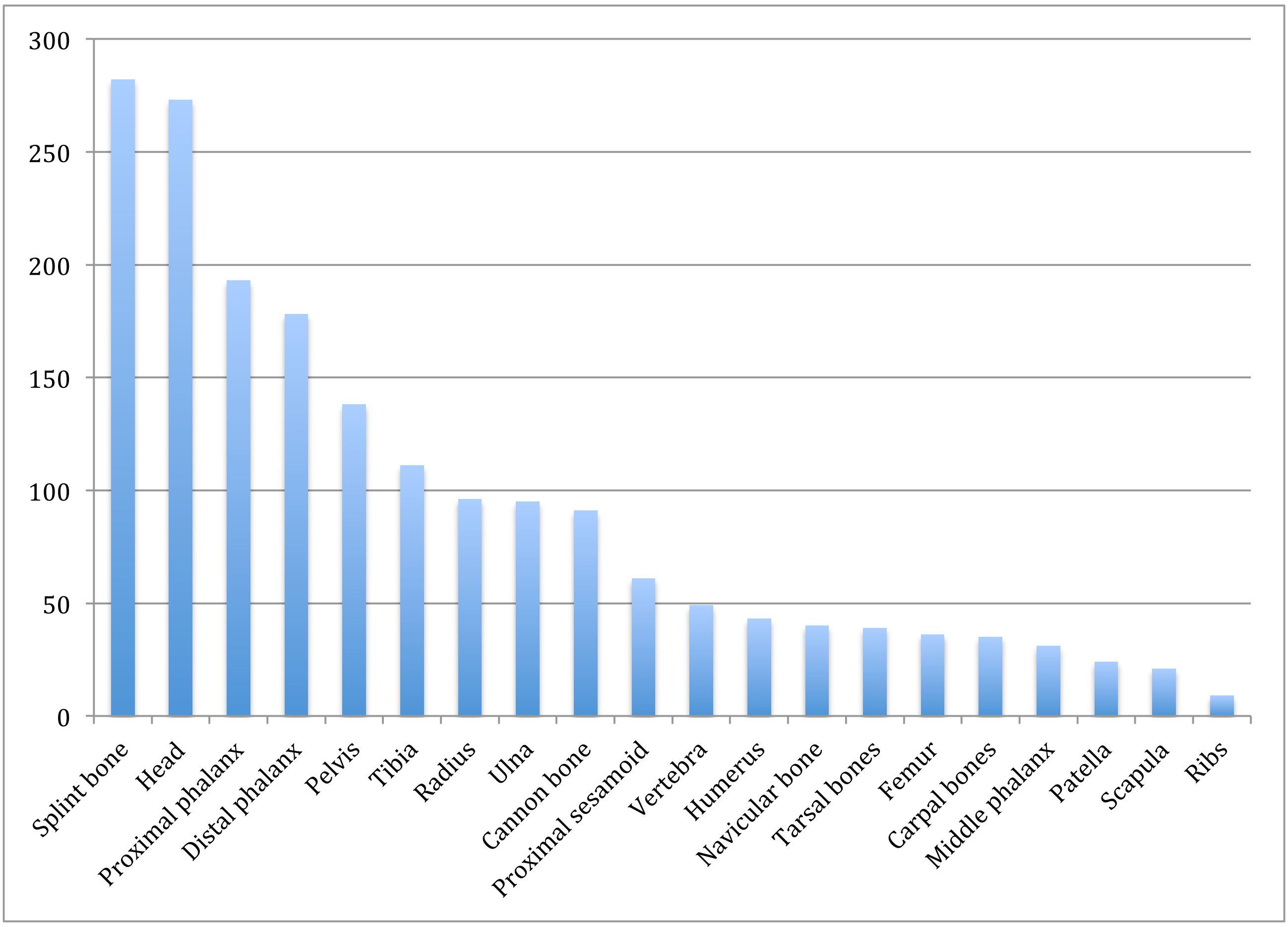


Fig 4: Distribution of fractures by bone.

Overall, 1,512 fractures involved bones of the limbs (including the pelvis); there were 390 fractures in the left forelimb, 383 in the right forelimb, 349 in the left hind limb, and 387 in the right hind limb. The affected limb was unknown in 3 cases. Of the 1,512 bone fractures affecting limbs, the lameness grade was 0 (no lameness) in 30 (2.1%), I/V in 125 (8.8%), II/V in 296 (20.9%), III/V in 292 (20.6%), IV/V in 325 (22.9%) and V/V in 324 (22.8%) cases. Lameness could not be scored in 28 (2.0%) recumbent horses and seven (0.4%) with ataxia, and the grade of lameness was not available in 94 (5.1%) horses. The fracture was simple in 930 (50.4%) cases, comminuted in 505 (27.4%), a fissure in 291 (15.8%) and an impression fracture in 85 (4.6%). Salter-Harris fractures were least common and occurred in 24 (1.3%) horses, and in the remaining 10 (0.5%) cases, no description of the fracture configuration was available. The fractures were open in 517 (28.0%) cases and closed in 1,276 (69.2%), and in the remaining 52 (2.8%), this information was not available.

*Therapy and outcome*

Of the 1,854 cases, 666 (36.1%) were treated conservatively, 654 (35.5%) underwent osteosynthesis with plates and/or screws, 209 (11.3%) had other surgical treatment under general anaesthesia and the remaining 316 (17.1%) were euthanased at the time of admission (Fig 5). The outcome was successful in 1,360 horses (73.7%), and the overall success rate of treated horses was 90.0%.

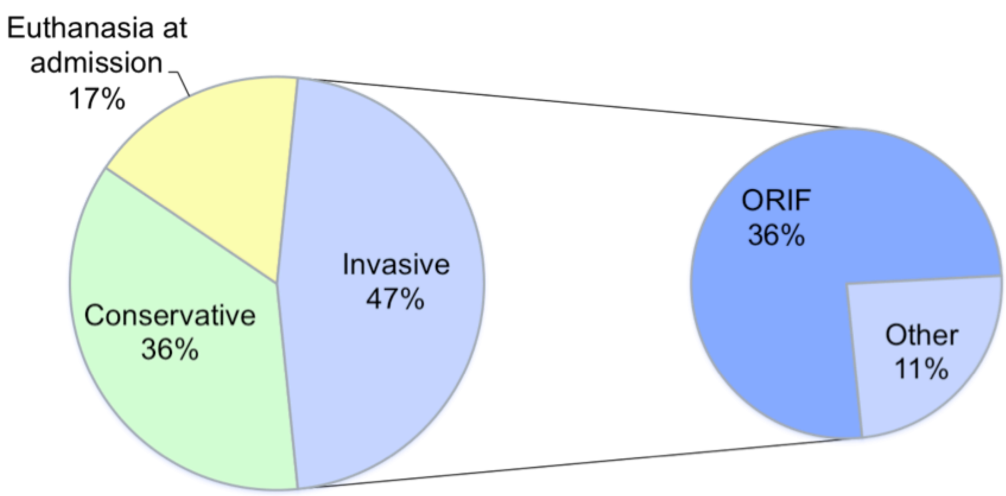


Fig 5: Distribution of therapies chosen for fracture management.

### 4.3.2 Analytic statistics

*Signalment*

Fractures caused by a kick occurred significantly more often in aged horses ($p<0.001$, OR=1.73) than in horses of other age groups and significantly more often in females than in males ($p=0.011$, OR=1.36). Ponies were 2.95x and Icelandic horses 6.27x more likely to suffer from fractures after a kick than other breeds. In contrast, warmbloods were 1.8x ($p<0.001$) and competition horses 1.5x ($p<0.001$) less likely to incur a fracture from a kick compared with other breeds. Fractures were more often caused by a kick in light horses than in heavy horses ($p<0.001$, OR=2.51). Fractures occurred significantly more often in foals and older horses in permanent group housing ($p<0.001$, OR=2.64 and $p=0.006$, OR=1.49, respectively) and in adult horses at the racetrack or in an arena ($p<0.001$, OR=3.52) compared with other locations. Ponies and Icelandic horses were more likely to be group housed ($p<0.001$, OR=2.53 and $p<0.001$, OR=8.25, respectively).

*History*

Of 356 kicks with a known environmental location, 237 (66.6%) occurred on pasture and 98 (27.5%) in a permanent group housing system. Fractures caused by kicks were more frequent in bones of the proximal limb ($p<0.001$, OR=2.01), especially the ulna (OR=11.34), radius (OR=11.34), tibia (OR=3.77), second and fourth metatarsal bones (OR=3.9) and humerus (OR=2.03). Exceptions were fractures of the pelvis and femur, which were less often caused by a kick than fractures of other bones (OR=0.17 and OR=0.28 respectively). In general, horses with fractures caused by a kick were presented for clinical examination later than horses with fractures attributable to other causes ($p=0.002$, OR=0.67). Owners that were aware of the cause of the fracture were 2.73x more likely to present the horse within 2 days of the injury. Fractures caused by a kick were 2.65x ($p<0.001$) more likely to be open than fractures attributable to other causes, but there was no significant association with the degree of comminution.

*Outcome*

Fractures caused by a kick had a more favourable outcome than fractures attributable to other causes ($p<0.001$), and the worst outcome occurred in horses with fractures caused by a fall ($p<0.001$, OR=1.97). There were highly significant differences in outcome depending on which bone was fractured. The worst outcomes were seen in horses with fractures of the femur ($p<0.001$, 6.68x more likely to be euthanased), middle phalanx ($p<0.001$, 5.29x more likely to be euthanased) and radius ($p<0.001$, 3.29x more likely to be euthanased). Horses with fractures of the splint bones of the hind limbs ($p<0.001$, 10.36x more likely to survive) and forelimbs ($p<0.001$, 7.63x more likely to survive), proximal sesamoid bones ($p=0.001$, 7.14x more likely to survive) and skull bones ($p<0.001$, 3.29x more likely to survive) had the best outcomes. Multivariate step back logistic regression showed that outcome was adversely affected by acute presentation ($p<0.001$, OR=3.75), grade 4 and 5 lameness ($p<0.001$, OR=10.31) and comminuted fracture ($p<0.001$, OR=3.15). There was no association between contamination of the fracture site and outcome. Open fractures had a worse outcome compared to closed only when long weight-bearing bones were involved ($p<0.001$, OR=2.31). Body weight of the animal did not affect the outcome of fractures, even when long weight-bearing bones were affected ($p=0.65$).

## 4.4 Discussion

Important goals of epidemiological studies of fractures in horses should include the determination of risk factors as well as factors affecting treatment outcome. This information could aid in minimising exposure of horses to risk factors, improve decisions making with regard to treatment and provide owners with a more accurate prognosis.

The results of the present study showed that kicks from other horses were the single most common cause of fractures in horses presented to our clinic and accounted for 43.6% of all fractures with a known cause. These results support our first hypothesis. Derungs et al. (2004) determined that kicks often result in a fracture, but most studies of the epidemiology of fractures have focussed on racehorses and on fractures that occurred during training or racing.[2-5] Fractures resulting from kicks are not common in racehorses because most of these horses have no or very little physical contact with other horses.

Group housing of horses has become increasingly popular in Switzerland, and we felt that its role in the occurrence of fractures was worth investigating. The finding that fractures occurred commonly in horses pastured in a group and in other permanent group-housing systems was not surprising and in agreement with the results of a study of free-ranging Przewalski horses.[21] Horses on pasture have the opportunity to run and engage in other high-energy activities, which may occur more often after they have been in a box stall for part of the day. This makes them prone to fractures because of falls, collisions with objects and kicks from herd mates. Our results showed that kicks from other horses often affect the limbs, particularly bones proximal to the first phalanx, which is in agreement with the findings of another study.[14] Derungs et al. (2004) found that the most common site of kicking injuries was at the level of the metacarpal/metatarsal bones, and fractures in this region were indeed numerous in our case series. It was interesting that fractures of the second and fourth metatarsal bones were significantly more often caused by kicks than second and fourth metacarpal bone fractures, which are probably more often self-inflicted. Kicks from other horses are the cause of fractures in many long bones, which tend to break after a kick because of their structure, location and sparse soft tissue coverage (Fig 6). [1,22,23]

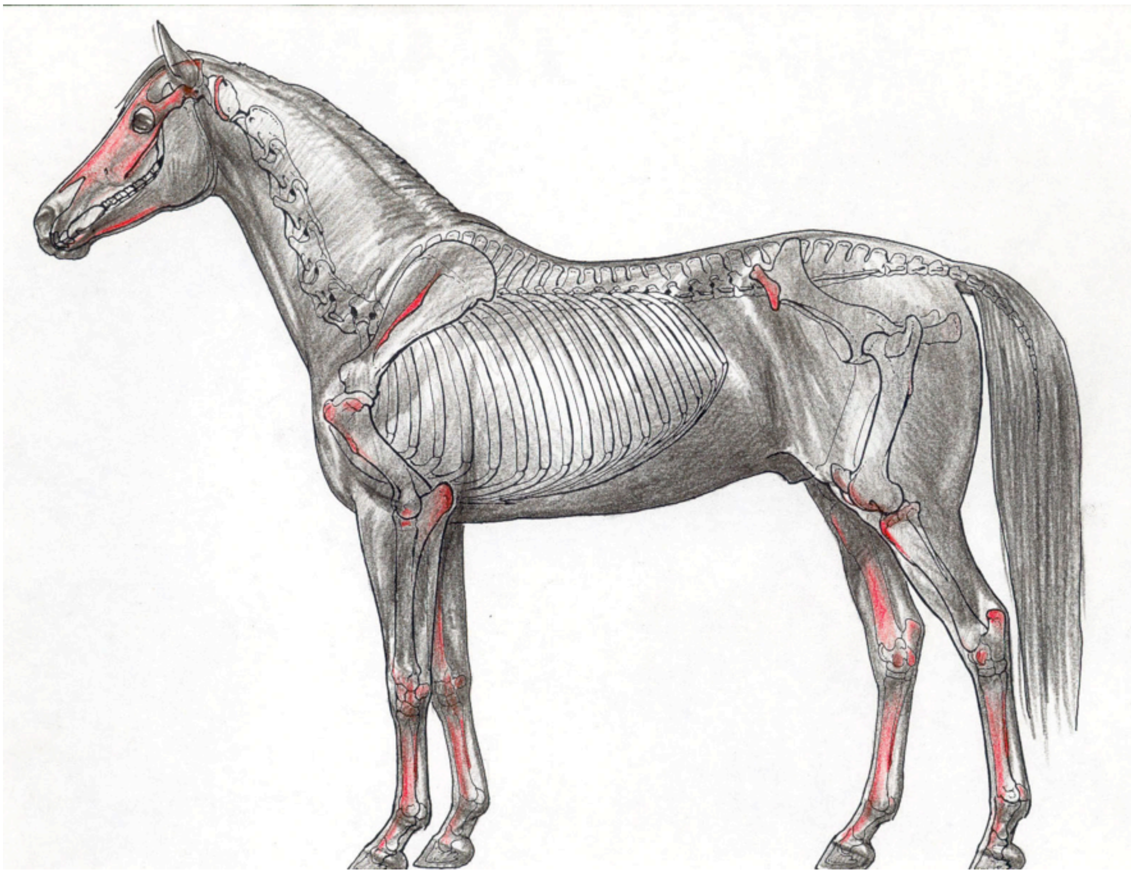

Fig 6: Illustration showing locations of bones with little soft tissue protection that are commonly fractured by a kick from another equid. Metacarpal/metatarsal bones, bony prominences such as the olecranon or the tuber coxae, and bones located directly under the skin such as the skull, the medial tibia, and the splint bones are particularly vulnerable.

Long bones are not well adapted to resist bending forces[24] that occur when the lateral or medial aspect of the bone is kicked. Mares engaged in fighting are more likely to kick than rear, and rearing is seen more commonly in fighting stallions.[25] Data on the horses that caused the fractures were not available in the present study. Interestingly, more female horses sustained kick injuries even though males were overrepresented in our caseload. Derungs et al. [23] reported that fissure fractures caused by a kick injury occur more often in aged horses than in young horses, which is in agreement with our findings (Fig 7).

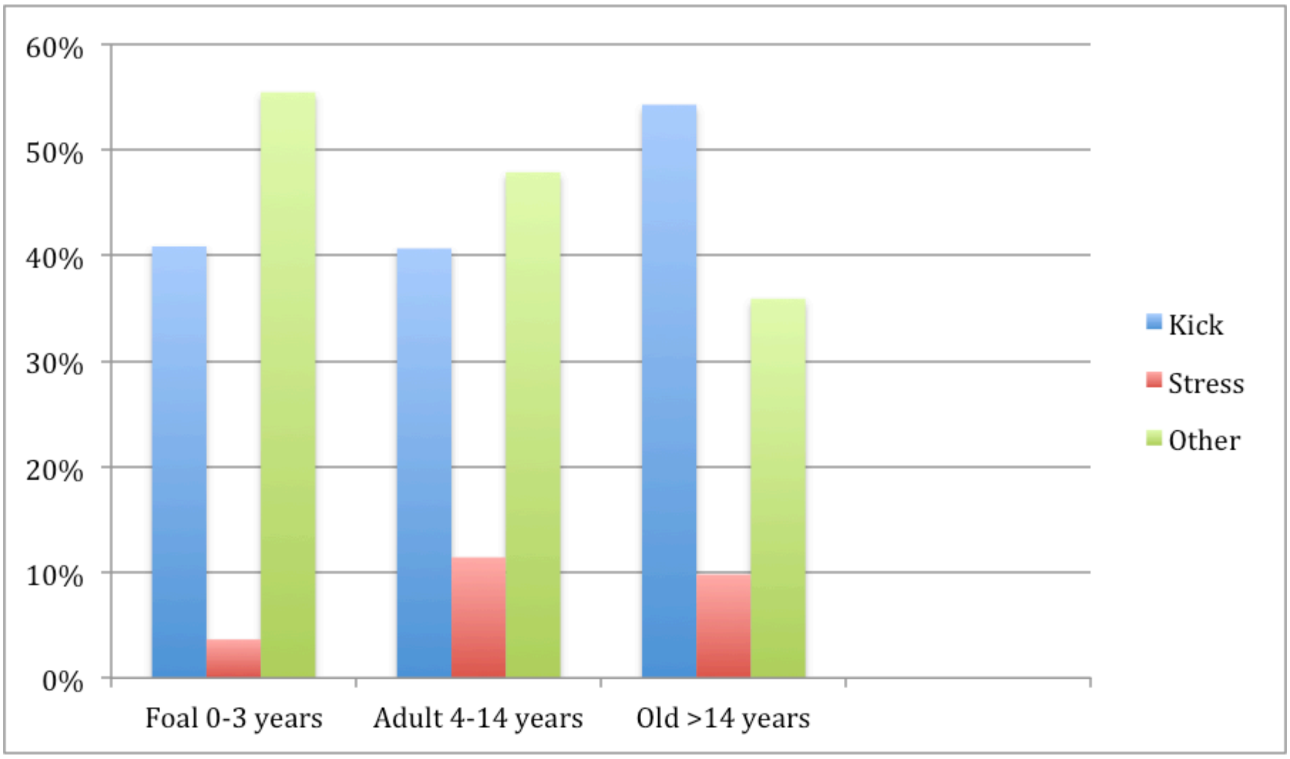


Fig 7: The distribution of fractures attributable to a kick, bone stress and other causes in the various age groups. It is important to note the increased percentage of stress fractures in adult equids compared with foals, and the increased percentage of fractures caused by a kick in aged horses compared with adults and foals.

It has been postulated that bone degeneration or senile osteopenia, which has been described in humans,[26] in dogs and cats[27] and in horses,[28] is the underlying cause of fissure fractures. Age-related bone changes make older horses more prone to fractures in general and not only to fractures caused by a kick. Another plausible explanation for the overrepresentation of aged horses with a fissure fracture is that old retired horses usually are housed in groups and therefore more at risk of being kicked. In contrast, adult equine competition horses often are housed in individual box stalls, and fractures in these horses usually are associated with load and strain during work. We also observed a high frequency of fractures caused by a kick in ponies and Icelandic horses. A possible explanation for this is that these horses almost always are kept in groups and thus have a higher risk of being kicked. Our results also showed that fractures in horses lighter than 400 kg, which included ponies and Icelandic horses, were significantly more often caused by a kick than by other factors.

With regard to age, use, breed, body weight and affected bones our study revealed different results compared to other epidemiological studies.[5] The most commonly fractured bones in racehorses are the third metacarpal bone, small carpal bones, ilium and tibia[5], whereas in our study population, the splint bone, skull, and proximal and distal phalanges were the most commonly fractured bones. Reports of skull fractures in horses are sparse and usually occur during falls and collisions but not during racing.[29] In the present study, skull fractures were most commonly caused by a kick, collision with an object or pulling back abruptly after entrapment of the head.

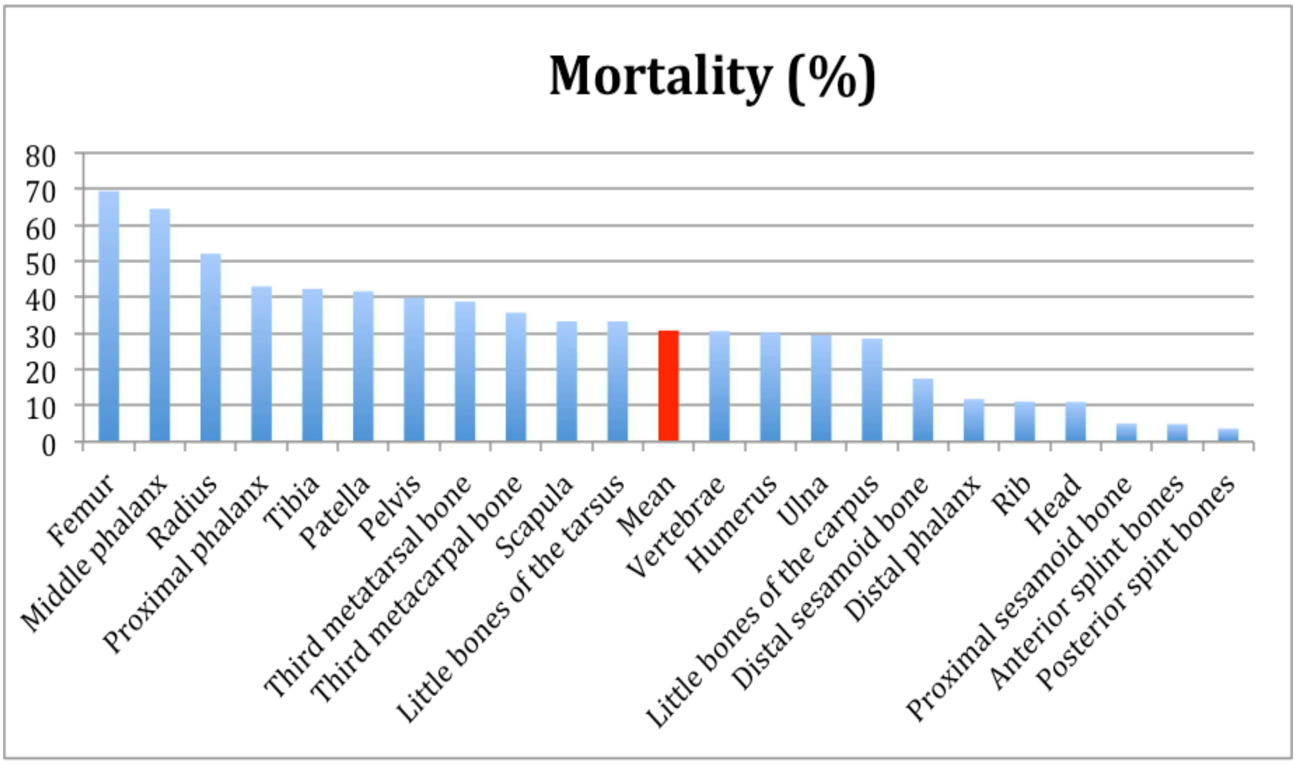


Fig 8: The number of horses that died from fractures of various bones. Equids with fractures of long weight-bearing bones and bones of the distal limb had the highest mortality rates.

In the present study, a successful outcome was seen in 73.8% of cases, which was similar to 71.7% reported in another study.[14] The main factor associated with outcome was the type of bone involved (Fig 8). Based on our findings, we rejected the hypothesis that fractures attributable to a kick have a worse outcome than fractures attributable to other causes. A factor that contributed to the rejection was that many kick injuries resulted in fissure or splint bone fractures that had a favourable outcome.

Acute fracture, grade 4 or 5 lameness and comminuted fracture, which often occurred in combination, had an adverse effect on outcome. Severe comminuted limb fractures usually result in severe lameness, which prompts the owner to call a veterinarian quickly. Of interest, the weight of the horses did not have a negative effect on outcome, even in fractures of weight-bearing long bones. One factor that may have contributed to this was that the horses in our study represented a referred population. All horses were examined initially by the primary care veterinarian, and some horses with catastrophic fractures or a poor prognosis may have been euthanased immediately. Equine patients with a low body weight included foals, which are fragile, predisposed to infection and often of lower financial value. Furthermore, fissure fractures are rare in light patients (foals and ponies), whereas complete or comminuted fractures are more common and have a worse prognosis. A bias generated by the large number of variables and their interrelationships may have obscured the effect of weight on the outcome of a fracture.

Auer (2012)[1] stated that for most fractures, nonsurgical management is not the treatment of choice and should not be advocated. However, conservative treatment was used in about one third of all cases presented here and was a reasonable choice for the treatment of fissure fractures or pelvic fractures.

In conclusion, kicks from other horses were the single most important cause of fractures in our mixed-breed horse population, and fractures caused by a kick did not have a worse outcome than fractures attributable to other causes. Outcome was primarily affected by the type of fractured bone but also by the degree of comminution and severity of lameness at the time of presentation.

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# 5. Part II: Metal plate removal after osteosynthesis in horses: a retrospective study

## 5.1 Introduction

Anatomic reduction and internal fixation are the requisites for early return to function after many fractures in both humans and horses.[1,2] The use of metallic implants such as locking compression plates (LCPs) has proved to be the therapy of choice for many fractures in horses.[3,4]

It is often challenging for surgeons to decide whether or not a metal implant should be removed once fracture healing is complete. In human medicine, routine removal of metal implants has been extensively questioned for safety reasons as well as for financial concerns.[5-8] A study at one Finnish hospital showed that over a 7-year period, 81% of implants were removed, which was the equivalent of 29% of all elective orthopedic surgeries and 15% of all orthopedic surgeries at that institution.[9] Many surgeons believe that removal of metal implants should not be a routine procedure and only patients with clear indications should undergo implant removal.[10] However, this is a controversial issue because clear evidence-based guidelines for identification of candidates for implant removal are lacking, even in human medicine.[10,11] In a meta-analysis of 14 studies that included 635 cases of forearm plate removal in humans, it was determined that 30.9% of patients had symptoms associated with implants.[12] Common indications for implant removal in humans include pain, implant failure, metal allergy, peri-prosthetic fracture, functional limitation, and infection.[13-15] Implants in children are routinely removed[10,11], and it is imperative to remove them as soon as possible when growth plates are compromised.

Removal of implants that cause symptoms is usually associated with good results in humans; the findings of a patient survey showed that 91% of symptomatic patients had considerable improvement or complete relief after implant removal.[14] However, removal does not always guarantee pain relief[16] nor is it a procedure without potential complications, which range from 3 to 40% in human medicine[12,14,17-20] and include nerve lesions, impaired wound healing, infection, incomplete removal, and refracture.[13,20,21] Müller et al. (1979) defined refracture as a fracture that occurs in the region of a previous fracture after the bone has undergone union clinically and radiographically and can tolerate a load similar to normal bone.[22] The resulting fracture line may conincide with the original fracture line or it may be located remote from the original fracture but within the area of bone undergoing changes due to fracture and treatment.[22] Refracture rates after implant removal in human medicine range from 0 to 30%, depending on the study.[22-25]

Although there are risks associated with implant removal, studies show that by leaving implants *in situ* they may interfere with future diagnostic procedures and surgeries or cause late infection, neoplastic degeneration, allergy, and peri-prosthetic fracture.[5,13,18,26]

To the authors' knowledge, there are no published studies on implant removal in horses or guidelines for surgical metal implant removal in veterinary medicine.

The most common indication for plate removal after tibial plateau levelling osteotomy in dogs is local bacterial infection and inflammation.[27] In horses, postoperative infection of orthopaedic implants is common,[28] and implant loosening associated with infection is an unequivocal indication for plate removal.[2,29] While it is evident that implants involving growth plates in foals must be removed to avoid disruption of normal bone growth, it is common to remove all devices that may later interfere with athletic function in young horses.[30]

The aim of the present retrospective study was to describe plate removal interventions in horses, focusing on the indications, timing, and outcome of the procedure.

## 5.2 Materials and methods

The medical records of horses presented to our Equine Hospital, between January 1990 and December 2015, for the removal of metal plates after fracture fixation were reviewed. Patients presented for the removal of a single retained screw or residual pieces of broken screws were excluded from the study. The sex, breed, age, and weight of the horses were recorded, and the affected bone, type of fracture (simple, comminuted, incomplete or Salter Harris) and degree of contamination (open or closed) were retrieved from radiographic reports prepared by a board certified radiologist (FDC). The number of surgeries, number of inserted and extracted plates, and time frame between fracture fixation and implant removal were noted. Indications for removal of the implants were classified as infection (presence of fistula, local swelling and heat, or presence of a lytic area around the implants on radiographs), lameness, or prevention of bone growth and development abnormalities (in foals). Before surgery, each horse underwent a clinical and orthopaedic examination by a board certified senior equine veterinary surgeon (MJ, AF). The degree of lameness and need for implant removal were determined. In cases with clinical signs not clearly attributable to the implants, nerve blocks were carried out to localize the origin of the pain. A complete radiographic study of the plated bone was done, and the owner informed about the procedure. Additional retrieved data included surgical and anesthesia time, intra-operative complications, and whether a hydro-pool system was used for post-operative recovery. The outcome was deemed successful in horses that were sound 3 months postoperatively, i.e. complaints related to the implant were resolved and, in cases of elective surgery, the patient was discharged without complications or with resolved minor complications. The outcome was considered unsuccessful when there was no substantial improvement at follow up examinations (persistent lameness or infection still present >3 months after implant removal) or a major complication such as refracture occurred.

## 5.3 Results

The results are summarized in Table 1.

| Patient Number | Sex of horse | Breed of horse | Weight of horse | Fractured bone | Fracture configuration | Number of inserted plates | Simoultaneous removal of multiple plates | Main indication for plate removal | Age (Years) at removal of the first (and second) plate | Time (months) from ORIF to removal of the first (and second) plate | General anesthesia | N° of removed plates total | Complications | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Female | Warmblood | 530 | Mandible | Comminuted | 1 | | Infection | 4 | 5 | Yes | 1 | None | Persistent infection |
| 2 | Female | Warmblood | 120 | Cannon bone | Comminuted | 1 | | Preventive | 0.42 | 4 | Yes | 1 | None | Successful |
| 3 | Gelding | Warmblood | 500 | Mandible | Simple | 1 | | Infection | 17 | 6 | Yes | 1 | None | Successful |
| 4 | Stallion | Warmblood | 260 | Proximal phalanx | Salter-Harris | 1 | | Preventive | 0.67 | 2 | Yes | 1 | None | Successful |
| 5 | Female | Warmblood | 580 | Splint bone | Simple | 1 | | Lameness | 4 | 8 | Yes | 1 | None | Successful |
| 6 | Stallion | Thoroughbred | 190 | Cannon bone | Simple | 2 | Yes | Preventive | 0.45 | 5 | Yes | 2 | None | Successful |
| 7 | Gelding | Warmblood | 590 | Mandible | Simple | 1 | | Infection | 12 | 2 | Yes | 1 | None | Successful |
| 8 | Female | Warmblood | 240 | Ulna | Simple | 1 | | Preventive | 2 | 15 | Yes | 1 | None | Successful |
| 9 | Female | Quarter Horse | 50 | Cannon bone | Simple | 2 | Yes | Preventive | 0.43 | 5 | Yes | 2 | None | Successful |
| 10 | Female | Warmblood | 140 | Mandible | Simple | 2 | Yes | Preventive | 0.34 | 2 | Yes | 2 | None | Successful |
| 11 | Gelding | Warmblood | 520 | Mandible | Fissure | 2 | Yes | Infection | 13 | 2 | Yes | 2 | None | Successful |
| 12 | Female | Warmblood | 600 | Ulna | Simple | 1 | | Lameness | 6 | 23 | Yes | 1 | None | Successful |
| 13 | Stallion | Warmblood | 200 | Cannon bone | Simple | 1 | | Preventive | 0.5 | 6 | Yes | 1 | None | Successful |
| 14 | Female | Icelandic Pony | 300 | Tibia | Comminuted | 2 | No | Infection | 21 (22) | 11 (14) | Yes (Yes) | 2 | Refracture | Euthanasia |
| 15 | Gelding | Icelandic Pony | 380 | Tibia | Simple | 2 | Yes | Lameness | 9 | 18 | Yes | 2 | None | Successful |
| 16 | Gelding | Pony | 120 | Tibia | Simple | 2 | Yes | Infection | 8 | 5 | Yes | 2 | Refracture | Euthanasia |
| 17 | Gelding | Warmblood | 50 | Cannon bone | Simple | 1 | | Preventive | 0.34 | 4 | Yes | 1 | None | Successful |
| 18 | Female | Haflinger | 40 | Radius | Simple | 2 | Yes | Preventive | 0.25 | 3 | Yes | 2 | None | Successful |
| 19 | Female | Warmblood | 150 | Femur | Salter-Harris | 2 | Yes | Preventive | 0.34 | 2 | Yes | 2 | Infection | Successful |
| 20 | Stallion | Warmblood | 145 | Cannon bone | Comminuted | 2 | Yes | Preventive | 0.67 | 6 | Yes | 2 | None | Successful |
| 21 | Female | Icelandic Pony | 365 | Cannon bone | Simple | 2 | Yes | Lameness | 9 | 10 | Yes | 2 | None | Successful |
| 22 | Stallion | Thoroughbred | 480 | Cannon bone | Simple | 1 | | Lameness | 3 | - | Yes | 1 | None | Successful |
| 23 | Female | Freiberger | 320 | Scapula | Simple | 1 | | Preventive | 1 | 7 | Yes | 1 | None | Successful |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | Stallion | Thoroughbred | 140 | Cannon bone | Simple | 2 | Yes | Preventive | 0.67 | 2 | Yes | 2 | None | Successful |
| 25 | Gelding | Friesian Horse | 530 | Ulna | Simple | 1 | | Infection | 5 | 4 | Yes | 1 | None | Persistent infection |
| 26 | Gelding | Warmblood | 510 | Splint bone | Comminuted | 1 | | Infection | 17 | 3 | Yes | 1 | None | Successful |
| 27 | Gelding | Warmblood | 585 | Mandible | Simple | 2 | Yes | Infection | 8 | 2 | Yes | 2 | None | Successful |
| 28 | Stallion | Warmblood | 240 | Proximal phalanx | Salter-Harris | 2 | Yes | Preventive | 0.67 | 2 | Yes | 2 | None | Successful |
| 29 | Stallion | Arabian | 390 | Ulna | Simple | 1 | | Lameness | 11 | 33 | Yes | 1 | None | Successful |
| 30 | Stallion | Warmblood | 530 | Ulna | Simple | 1 | | Lameness | 3 | 30 | Yes | 1 | None | Successful |
| 31 | Stallion | Warmblood | 550 | Mandible | Comminuted | 3 | Yes | Infection | 12 | 3 | Yes | 3 | None | Successful |
| 32 | Female | Pony | 240 | Mandible | Simple | 1 | | Infection | 13 | 4 | Yes | 1 | None | Persistent infection |
| 33 | Female | Warmblood | 250 | Ulna | Simple | 1 | | Preventive | 1 | 4 | Yes | 1 | Seroma | Successful |
| 34 | Female | Icelandic Pony | 300 | Ulna | Simple | 1 | | Infection | 5 | 6 | Yes | 1 | None | Successful |
| 35 | Gelding | Miscellaneous | 570 | Mandible | Comminuted | 1 | | Infection | 15 | 2 | No | 1 | None | Successful |
| 36 | Stallion | Pony | 90 | Radius | Comminuted | 2 | No | Infection | 6 (9) | 10 (36) | Yes (Yes) | 2 | None | Successful |
| 37 | Gelding | Warmblood | 590 | Cannon bone | Simple | 1 | | Lameness | 9 | 3 | Yes | 1 | None | Successful |
| 38 | Gelding | Donkey | 180 | Mandible | Comminuted | 1 | | Infection | 14 | 8 | Yes | 1 | None | Successful |
| 39 | Female | Warmblood | 180 | Radius | Simple | 1 | | Preventive | 0.34 | 4 | Yes | 1 | None | Successful |
| 40 | Female | Pony | 120 | Cannon bone | Simple | 2 | No | Infection | 4 (5) | 3 (13) | Yes (Yes) | 2 | None | Successful |
| 41 | Stallion | Miscellaneous | 360 | Cannon bone | Simple | 2 | No | Preventive | 2 (3) | 8 (13) | No (Yes) | 2 | None | Successful |
| 42 | Gelding | Warmblood | 530 | Mandible | Comminuted | 1 | | Infection | 7 | 5 | Yes | 1 | None | Persistent infection |
| 43 | Gelding | Warmblood | 440 | Radius | Comminuted | 2 | No | Infection | 14 | 2 | No | 1 | Refracture | Euthanasia |
| 44 | Gelding | Warmblood | 560 | Mandible | Simple | 2 | Yes | Infection | 7 | 3 | Yes | 2 | None | Successful |
| 45 | Stallion | Warmblood | 610 | Mandible | Comminuted | 1 | | Infection | 3 | 9 | Yes | 1 | None | Successful |
| 46 | Gelding | Pony | 400 | Ulna | Comminuted | 2 | Yes | Lameness | 14 | 12 | Yes | 2 | Refracture | Unsuccessful (re-operated) |
| 47 | Female | Warmblood | 620 | Ulna | Simple | 1 | | Lameness | 16 | 9 | Yes | 1 | None | Successful |
| 48 | Gelding | Donkey | 210 | Tibia | Simple | 2 | Yes | Infection | 12 | 8 | Yes | 2 | None | Successful |
| 49 | Stallion | Icelandic Pony | 310 | Radius | Comminuted | 2 | No | Infection | 9 | 3 | Yes | 1 | None | Persistent infection/ Nonunion |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | Gelding | Thoroughbred | 550 | Ulna | Comminuted | 1 | | Infection | 12 | 5 | Yes | 1 | None | Successful |
| 51 | Female | Icelandic Pony | 350 | Ulna | Simple | 1 | | Lameness | 16 | 9 | Yes | 1 | None | Successful |
| 52 | Female | Miscellaneous | 490 | Ulna | Simple | 1 | | Lameness | 6 | 9 | Yes | 1 | None | Successful |
| 53 | Female | Warmblood | 320 | Proximal phalanx | Salter-Harris | 2 | Yes | Preventive | 1 | 3 | Yes | 2 | None | Successful |
| 54 | Female | Icelandic Pony | 280 | Radius | Salter-Harris | 1 | | Preventive | 1 | 4 | Yes | 1 | None | Successful |
| 55 | Gelding | Thoroughbred | 450 | Radius | Fissure | 2 | No | Infection | 15 (15) | 27 (27, one day apart) | No (No) | 2 | None | Successful |
| 56 | Female | Warmblood | 300 | Ulna | Simple | 1 | | Preventive | 0.73 | 4 | Yes | 1 | None | Successful |
| 57 | Female | Warmblood | 550 | Ulna | Comminuted | 1 | | Infection | 15 | 7 | No | 1 | None | Successful |
| 58 | Gelding | Warmblood | 600 | Ulna | Simple | 1 | | Infection | 5 | 2 | No | 1 | None | Successful |
| 59 | Gelding | Warmblood | 520 | Mandible | Comminuted | 1 | | Infection | 10 | 2 | No | 1 | None | Persistent infection/ Nonunion |
| 60 | Female | Warmblood | 350 | Ulna | Simple | 1 | | Preventive | 2 | 5 | No | 1 | None | Successful |
| 61 | Gelding | Warmblood | 500 | Scapula | Simple | 1 | | Lameness | 12 | 13 | No | 1 | None | Successful |
| 62 | Stallion | Pony | 80 | Cannon bone | Comminuted | 2 | No | Lameness | 5 | 4 | Yes | 1 | None | Successful |
| 63 | Female | Icelandic Pony | 350 | Ulna | Simple | 1 | | Infection | 14 | 9 | Yes | 1 | None | Successful |
| 64 | Female | Miscellaneous | 250 | Ulna | Simple | 1 | | Preventive | 0.75 | 7 | Yes | 1 | None | Successful |
| 65 | Female | Warmblood | 570 | Ulna | Comminuted | 1 | | Infection | 9 | 2 | No | 1 | None | Successful |
| 66 | Gelding | Pony | | Cannon bone | Comminuted | 2 | No | Lameness | 9 | 11 | Yes | 1 | None | Successful |
| 67 | Gelding | Warmblood | 460 | Splint bone | Comminuted | 1 | | Infection | 14 | 1 | No | 1 | None | Successful |

Table 1: Overview of 67 horses that underwent open reduction and internal fixation using plates and subsequent plate removal.

*Population*

Sixty-seven horses met the requirements for inclusion in the study. There were 28 females and 39 males (24 geldings and 15 stallions) weighing a mean of 361 kg (range, 30-620 kg; median weight, 355 kg). The mean age of the horses was 7.3 years (range: 1 day - 21 years): 24 were ≤ 3 years old, 35 were 4 to 14 years old, and 8 were > 14 years old. Breeds included 36 Warmbloods, 15 ponies and Icelandic horses, 5 Thoroughbreds, and 11 other breeds. Affected bones were the ulna (19), third metatarsal and metacarpal bones (14), mandible (14), radius (7), tibia (4), proximal phalanx (3), splint bones (3), scapula (2), and femur (1).

*Original fracture configuration*

The fracture configuration was simple in 39 horses, comminuted in 21, Salter-Harris type II in 5 (3 proximal phalanges, 1 radius, and 1 femur) and incomplete in 2. Twenty-seven fractures were open and 40 were closed.

*Open reduction and internal fixation*

One plate was used for fracture fixation in 40 horses, 2 plates in 26 horses (9 third metacarpal/metatarsal bones, 5 radii, 4 mandibles, 4 tibiae, 2 proximal phalanges, 1 ulna, and 1 femur) and 3 plates were required in one mandibular fracture.

*Indications for removal*

The main indication for implant removal was infection of the plate, which occurred in 30 horses (10 of which showed concurrent lameness), followed by prevention of bone growth abnormalities in 22 foals (mean age 0.9 years), and lameness in another 15 horses (2 were lame only in the winter when the temperature was low).

*Implant removal surgery*

The overall mean interval from osteosynthesis to plate removal was 7.9 months (1-36 months). The mean interval was 5.1 months in young horses undergoing implant removal for preventive reasons, 7.4

months in horses with infection, and 13.7 months in horses that were lame. Of 27 horses with multiple plates, 18 had all implants removed in one operation. Of the remaining 9 horses, 5 underwent 2 surgeries to remove plates separately, 2 had only one plate removed, and another 2 had to be euthanized after removal of the first plate because of refracture. A total of 91 plates were removed during 72 different implant removal operations. Sixty operations were carried out with the horse recumbent under general anaesthesia and 12 with the horse standing and sedated. Of the 72 interventions, 55 had detailed surgery and anaesthesia reports, which showed that the mean surgery time was 115.3±46.6 minutes (range, 30-240 minutes) and the mean anaesthesia time was 153.6±53.0 minutes (range, 30-280 minutes). In 2 cases, single screws broke during implant removal and the remaining metallic material was left in place, but did not cause complications. Of 60 horses that underwent general anaesthesia, recovery was assisted by hand or by ropes in 55 and a hydro-pool system was used in 5. Depending on the affected bone, horses were prescribed up to 2 months of stall rest followed by a gradual increase in exercise.

*Complications of implant removal*

Overall, 6 horses (9%) had complications related to the surgery or to the recovery following general anaesthesia. There were 4 major complications (refractures) and 2 minor complications (1 foal with surgical site infection and 1 with a seroma at the surgical site).

*Outcome*

Removal of metallic implants had a successful outcome in 57 of 67 patients (85.1%) (Fig. 1 a-d) and included 21 of 30 patients with infection, 14 of 15 with lameness, and all 22 growing foals.

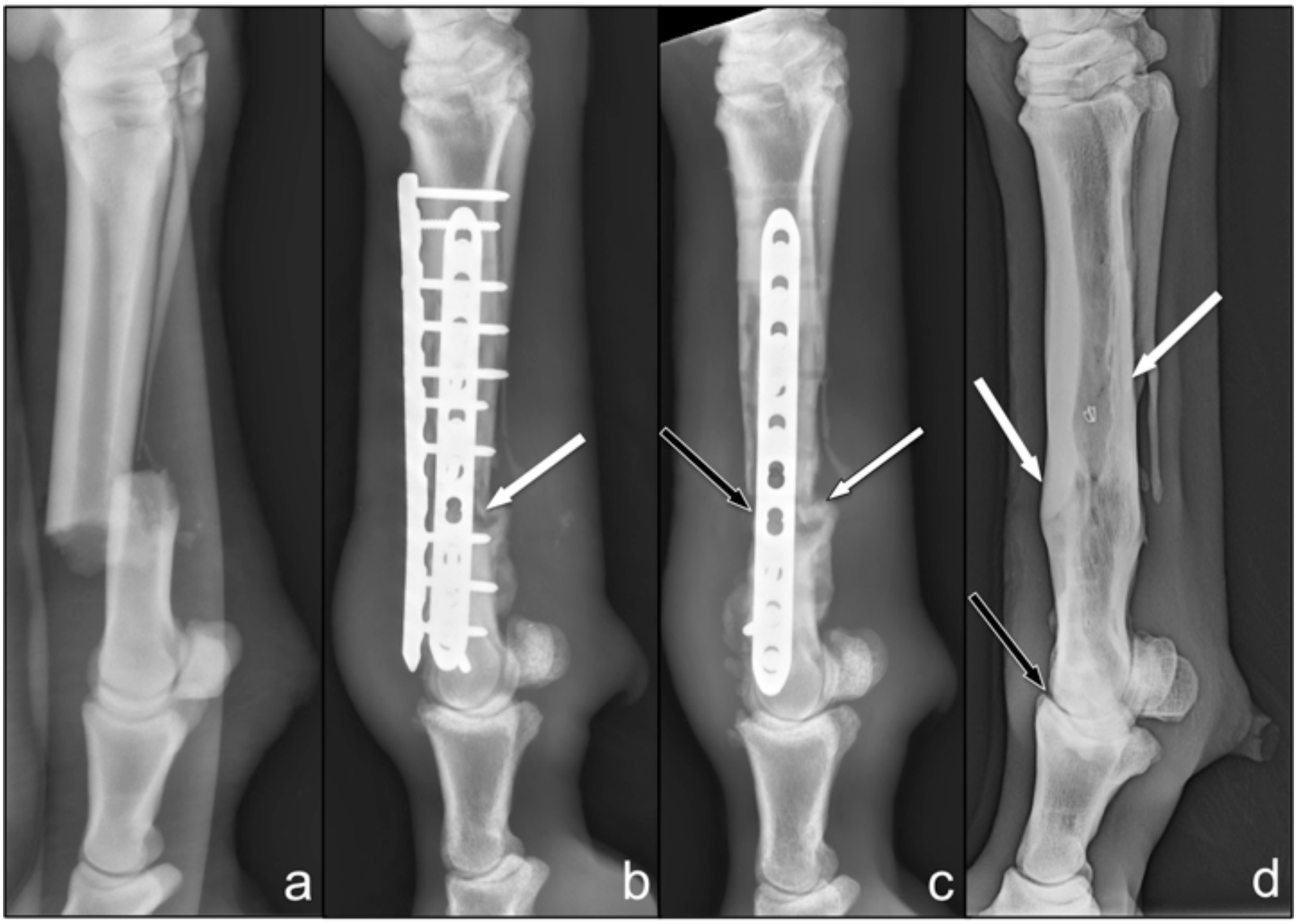


Fig 1: Latero-medial radiographic views of the right metatarsus before and at various times after osteosynthesis in a 5-year-old pony (case 42/43; 120kg). a) Acute open (contaminated) transverse mid-diaphyseal fracture with severe plantar dislocation, moderate shortening, outward rotation and concurrent transverse fracture and moderate angulation of both splint bones. b) At 80 days after open reduction and internal fixation (ORIF), there is incomplete healing of the fracture with an irregular area of lucency due to bone lysis (white arrow) and moderate soft tissue swelling, compatible with osteomyelitis. c) At 97 days after ORIF and 15 days after removal of the dorsal plate, an incomplete solid and irregular callus has formed in the area of the fracture (white arrow), chronic moderate soft tissue swelling is seen, the metatarsal bone has a generalized heterogenous radiopacity and there is a defect in the dorsal cortex (black arrow). d) At 4 years after ORIF and 3 years after removal of the lateral plate, the previous fractures have healed completely and the soft tissue swelling has resolved. In addition, there is remodeling of the distal metatarsal bone with focal widening at the level of the fracture and uneven cortical thickening (white arrows), generalized heterogenous radiopacity of the distal metaphysis of the metatarsal bone and progressive degenerative changes of the fetlock joint (black arrow).

Of 45 symptomatic horses (infection or lameness), 35 (77.8%) had considerable improvement or complete healing after plate removal. In cases with infection of double-plated bones, removal of only one implant was not effective and removal of the second plate was required at a later date.

Nine horses that had undergone plate removal because of infection had an unsatisfactory outcome: refracture occurred in 3 horses, and 6 had infection that did not resolve within 3 months despite removal of the implants. In 4 of these, the infection eventually resolved but the remaining 2 had severe nonunion and were euthanized. The only horse with an unsuccessful outcome among those with lameness suffered a refracture.

Three of 4 horses with refracture were immediately euthanized. A second osteosynthesis was carried out in the remaining horse, which had been presented for lameness and had no evidence of infection after fixation of the original comminuted fracture of the olecranon using 2 plates. Only one plate was used for fixation of the refracture, and the screws were placed in the existing holes (Fig. 2 a-d).

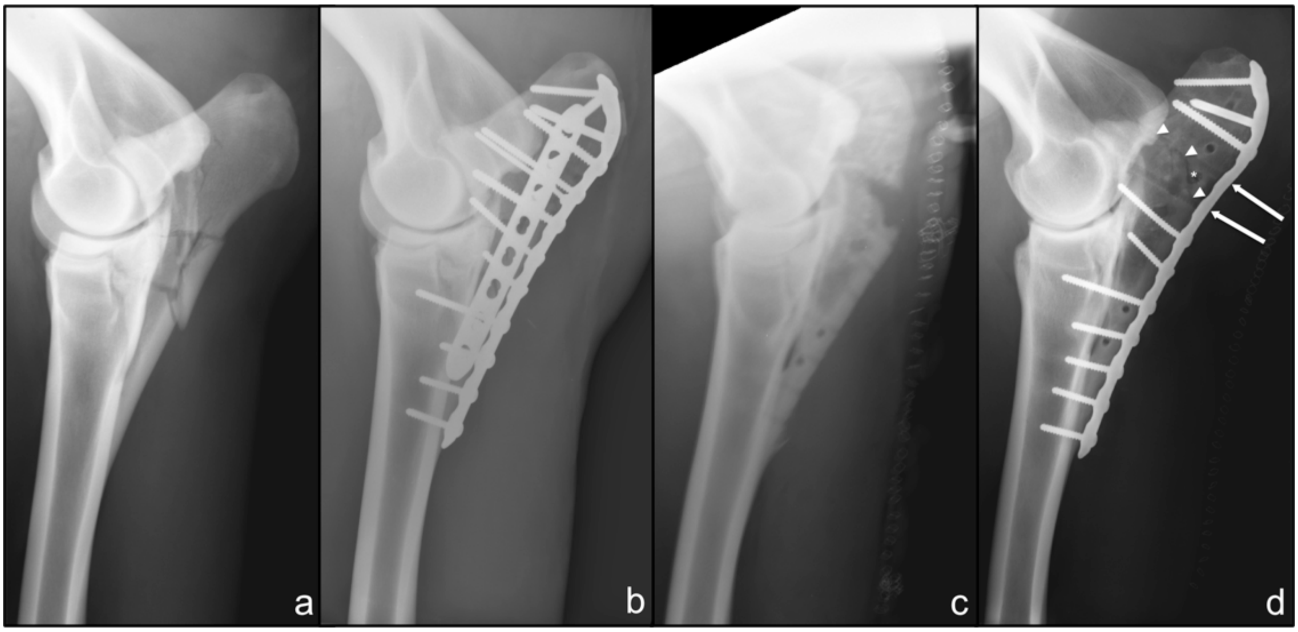


Fig 2: Latero-medial radiographic views of the right ulna before and at various times after osteosynthesis in a 14-year-old horse (case 50; 400 kg). a) An acute closed type 4 fracture of the olecranon with mild dislocation of the fragments. b) At 12 months after ORIF using 2 plates, the horse was presented with persistent lameness but no signs of infection, and radiographs showed consolidation of the fracture site and no signs of implant failure or osteomyelitis. c) At 12 months after ORIF and after removal of both plates under general anesthesia (motion blurred image), the horse fell during an attempt to rise in the recovery box and had a non-weight-bearing lameness afterwards. The radiograph shows an acute type 3 fracture partially coinciding with the original fracture line but running cranio-proximally instead. d) ORIF of the ulnar refracture was done using the same type of plate caudally with placement of screws in the existing holes. The refracture line is associated with 3 screw holes of the first fixation: 2 of the caudal plate (white arrows) and 1 of the lateral plate (*).

Follow-up examination of this horse at 2 years showed satisfactory results and no need for plate removal. The horse could be ridden normally, and the only owner complaint was sporadic episodes of stumbling.

*Refractures*

Refracture occurred in 4 adult horses (3 males and 1 female) with a mean age of 14.2 years (range: 8-22 years) and a mean weight of 315 kg (range: 120-440 kg) (Table 2).

| Case Nr. | Weight (kg) | Age (Years) | Fractured bone | Fracture description | Indication for plate removal | Time between osteosynthesis and plate removal (months) | Simultaneous plate removal | Refracture after removal of the first or second plate | General anesthe-sia | Day of refracture (after plate removal) | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 300 | 22 | Tibia | Comminuted, open, dislocated, articular | Infection | 14 | No | Second | Yes | Day 45 | Euthanasia |
| 16 | 120 | 8 | Tibia | Simple, closed, dislocated, non-articular | Infection | 5 | Yes | - | Yes | Day 2 | Euthanasia |
| 43 | 440 | 14 | Radius | Comminuted, closed, dislocated, non-articular | Infection | 2 | No | First | No | Day 1 | Euthanasia |
| 46 | 400 | 13 | Ulna | Comminuted, closed, dislocated, articular | Lameness | 12 | Yes | - | Yes | Day 1 | Reoperation with identical plate and uneventful follow-up |

Table 2: Refracture in four horses after open reduction and internal fracture fixation

There were 2 ponies (nos. 16 and 46), 1 Icelandic horse (no. 14) and 1 Warmblood horse (no. 43). Three of the 4 horses underwent implant removal because of infection and 1 because of chronic lameness. Three refractures occurred through the original fracture line and 1 was a peri-prosthetic fracture. All refractures occurred in long bones: 2 tibiae, 1 radius and 1 ulna. The original fracture was comminuted in 3 horses, and a double-plating technique was used for the original fracture repair in all 4 horses. The mean time interval from osteosynthesis to implant removal was 8.3 months (range 2 – 14 months). In cases 16 and 46, plates were removed simultaneously with the patients under general anesthesia, and refracture occurred during recovery. In case 43, the peri-prosthetic fracture occurred after removal of the first plate with the horse standing, and in case 14, refracture occurred 45 days after removal of the second plate. None of the 4 horses was recovered in a hydro-pool system.

## 5.4 Discussion

The results of the present study show that removal of metallic implants was successful in 85.1% of the horses and led to resolution of infection and lameness in 77.8% of those affected. Our results are in agreement with the success rates of implant removal reported in human medicine, which range from 50 to 91%.[14,16,31,32] The most common indication for plate removal in our study population was infection, which resolved after implant removal in more than 2/3 of horses. In the remaining horses, infection did not resolve within a reasonable time (3 months) despite pre- and postoperative antibiotic therapy, aseptic technique, and local debridement. Some of these horses were euthanized because of refracture or nonunion. The bones most commonly involved in plate removal were the ulna, mandible, and third metacarpal/metatarsal bones. Most mandibular fractures are open to the oral cavity, which explains the high infection rate (Fig. 3a-d).

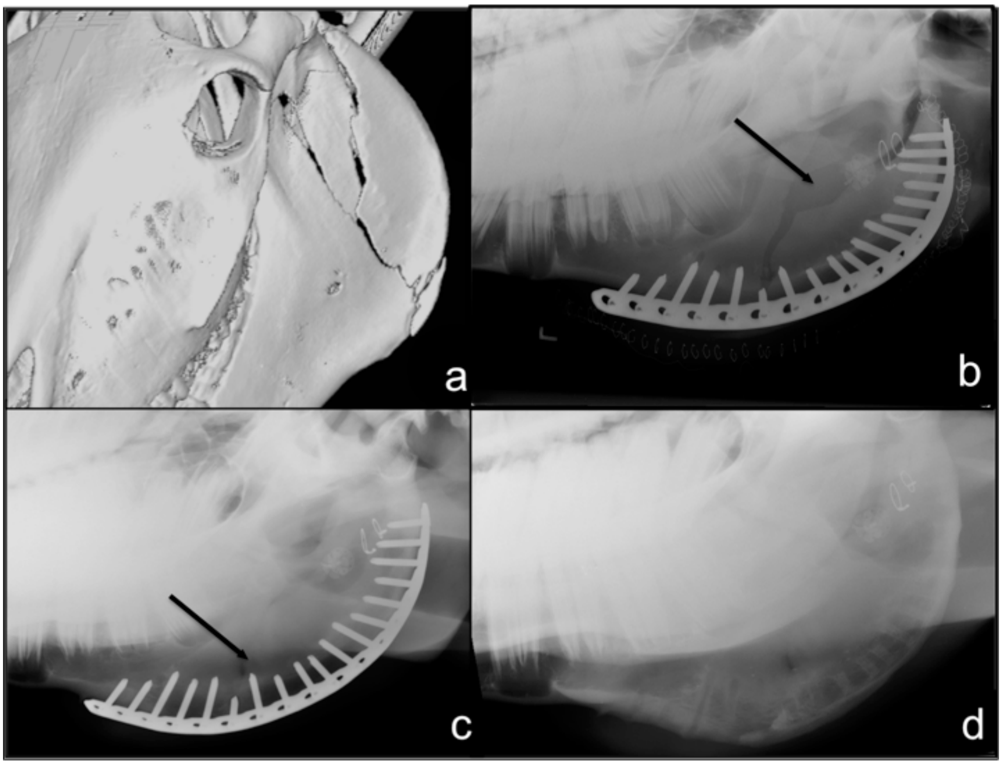


Fig 3: Lateral oblique volume-rendered CT image (a) and radiographs of a comminuted fracture of the left mandible before and at various times after osteosynthesis in a three-year-old horse (case 49: 610 kg). a) Volume-rendered computed tomographic image of a comminuted fracture of the left mandible. b) Lateral oblique radiographic view of the mandibular fracture immediately after ORIF showing the visible fracture gap (black arrow). c) At 8 months after ORIF, there is a poorly-defined area of discrete bony lysis (black arrow) that appears to be osteomyelitis. d) At 10 months after ORIF and 2 months after plate removal, there is complete healing of the mandibular fracture, but mild heterogenous radiopacity of the mandible is still present, which is consistent with persistent infection, and the screw holes are still visible.

Similarly, third metacarpal/metatarsal and ulnar fractures are often open and contaminated because there is little soft tissue protection over these bones. Many of these fractures are caused by kicks, which predispose to open fractures and infection and thus the potential need for implant removal at a later date.[33] A clear association between open fracture and the occurrence of orthopedic implant infection has been reported.[28] However, this was not seen in the present study, in which 16 of 27 (59%) open fractures and 14 of 40 (35%) closed fractures developed infection. Implant infection appears to be less of an issue in human medicine because it is not extensively dealt with.[5,6,12]

Infection usually is linked to the plate, which acts as a substrate for bacterial growth and formation of a biofilm.[34,35] It is very difficult and sometimes impossible to resolve infection associated with an implant even when broad-spectrum antimicrobials are used.[2] Local debridement and antimicrobial therapy can be effective in a subset of patients with infected orthopedic devices, but implant removal leads to better results in humans and dogs.[27,36] To the authors' knowledge, there are no studies that have investigated the predisposition of horses to infection or whether achieving asepsis in the equine patient is more difficult than in other species.

Before an implant is removed, it is important to determine that the bone is able to sustain a normal load, thereby reducing the risk of refracture in the recovery phase. In the present study, clinical and radiographic evaluations were carried out preoperatively to assess bone healing. However, these methods cannot assess the process of remodeling, which is of critical importance for regaining full load-bearing capacity, especially in weight-bearing long bones.[13] Evaluation of fracture healing via radiography can be difficult when metal implants are in place, especially when multiple plates are used. Moreover, radiographic signs of nonunion may be equivocal in cases with osteomyelitis or only visible later on. Some horses were presented with lameness but no apparent signs of infection. Osteomyleitis is not always apparent on radiographs and may require histological evaluation of tissue for a definitive diagnosis.[37] Thus, it is challenging to determine whether the cause of pain and subsequent lameness is infection. Probably the most important aspect of infected plates is that bacterial growth impairs bone healing. Often it is a race between loosening of the implant caused by the infection and healing of the fracture.[2]

In the present study, lameness was consistently associated to cold weather in a pony with a tibial fracture and an Icelandic horse with an ulnar fracture. It is possible that thermal conduction is higher in metal when there is very little soft tissue covering the plate. Reports of pain caused by cold temperatures in human patients with metal implants are lacking and therefore a comparison cannot be made.

Plate removal led to complications in 6 horses (9.0%), which is less than the lowest rate reported in human medicine.[12,17-20] A meta-analysis of 14 studies that included 635 cases of forearm plate removal in humans between 1984 and 2002 showed that the complication rate was 24% (range 11.8 – 40%).[12] However, the definition of complication has not been standardized and therefore caution must be exercised when comparing human and equine studies. A common complication of plate removal in human patients is nerve damage,[13,20] signs of which range from local skin anesthesia to motor weakness of the corresponding limb. In a study by Langkamer and Ackroyd (1990), nerve damage did not occur in human patients after osteosynthesis, but was seen after plate removal.[20] This was attributed to the fact that nerves can be easily identified when placing the plate, but subsequent formation of scar tissue makes fine dissection of tissues and identification of nerves difficult at the time of plate removal. Reports on nerve damage after metal implant removal in horses are lacking, and none of the horses in the present study developed clinical signs of nerve damage.

The two foals that developed minor complications related to wound healing (surgical site infection and seroma) underwent plate removal to prevent interference with bone growth. Both were easily managed in our clinic, had an unremarkable recovery, and were sound at the time of discharge. The risk of minor complications such as these is justifiable considering the importance of optimizing normal bone development via implant removal.

Refracture was the worst complication in the present study and accounted for 6% (4/67) of cases, compared with frequencies of up to 30% reported in human medicine.[38] Studies in human medicine have shown that many refractures occur at the site of the original fracture and in the absence of major trauma.[8,23,24,38] Hidaka and Gustilo (1984) suggested three possible causes for refracture: cortical thinning secondary to diminished load transfer, avascularity of the cortex beneath the plate, and an osteolytic process that weakens the bone beneath the plate.[38] More recent studies have shown that bone weakness after removal of implants is related more to the presence of residual screw holes than to cortical atrophy.[39] Avascularity of the cortex beneath the plate has become less frequent because of the development of newer low contact plates. A common osteolytic process seen in horses is infection of the internal fixation device, which can lead to osteolysis, sequestra, loss of stability, and nonunion[35]. However, this potential cause of refracture suggested by Hidaka and Gustilo[38] does not fit the definition by Müller et al. who defined refracture as a fracture occurring after the bone has solidly bridged and is able to bear weight.[22] Adhering to this definition, the term refracture should not be used when a fracture occurs in association with nonunion after plate removal, and we considered cases with an unsuccessful outcome separately when there was severe osteomyelitis and possible nonunion. Incorrect preoperative assessment rather than plate removal *per se* led to the unsuccessful outcome in these cases. Although we were aware that union may not have been complete in 2 of our cases, the implant was removed because infection could not be resolved and removal was the only option. Radiographs of these 2 horses showed equivocal union. It cannot be ruled out that the 3 cases of refracture that occurred after the removal of infected implants had some degree of malunion, and it must be considered that preoperative assessment of bone healing can be difficult under these circumstances.

Another study showed that refracture rate in human patients was clearly associated with the use of large 4.5-mm dynamic compression plates, plate removal less than 12 months after surgery, poor anatomical reduction, and open fractures.[12] The type of plate was not considered a variable in our study because of missing data and changes in plate design and materials over the years.

Some refractures do not run through the region of the original fracture, but instead originate in the area of the plate ends, and are called peri-prosthetic fractures.[5] In the present study, one horse suffered a peri-prosthetic radius fracture after removal of the first plate with the horse sedated and standing (Fig. 4a-d); the refracture line passed just above the remaining plate and not in the area of the original fracture line.

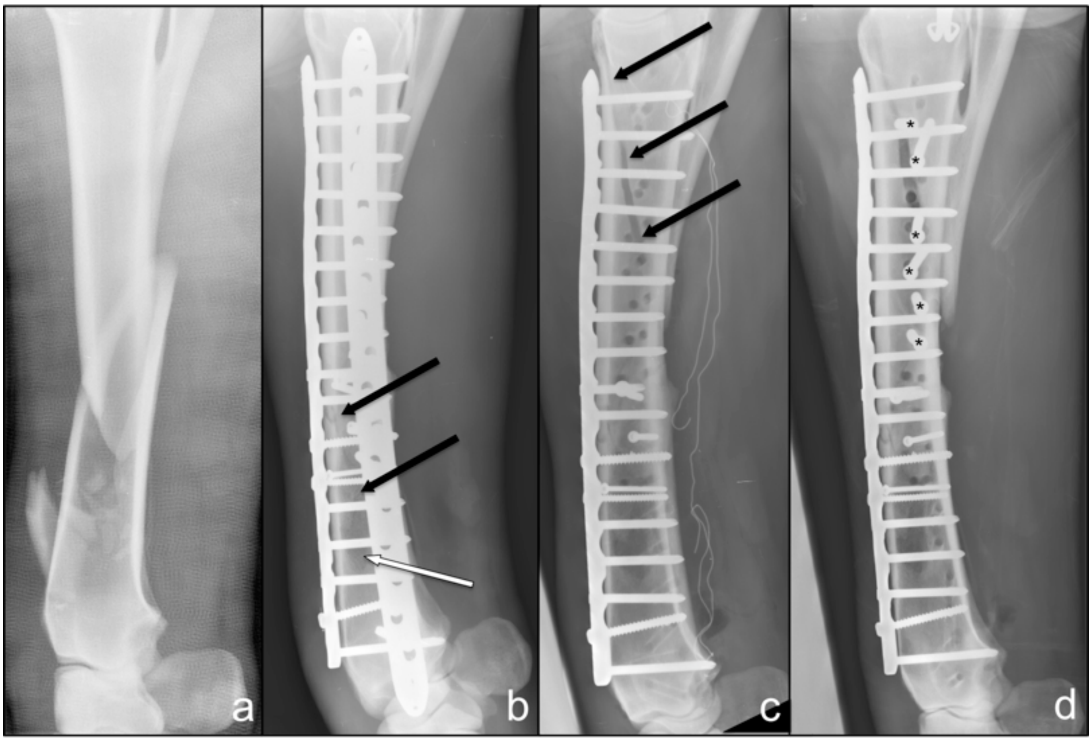


Fig 4: Latero-medial radiographic views of a right radius fracture before and at various times after osteosynthesis in a 14-year-old horse (case 47; 440 kg). a) Acute comminuted mid-diaphyseal radius fracture with moderate dislocation, mild shortening, and angulation. b) At 80 days post ORIF using 2 plates, there is delayed healing of the fracture and the original fracture lines are still visible dorsally (black arrows). An area of irregular defined bone lysis (white arrow) and moderate associated soft tissue swelling compatible with osteomyelitis are seen. c) At 82 days post ORIF and after standing removal of the lateral plate, a periprosthetic fracture (black arrows) originating at the level of the proximal part of the plate and running from cranio-proximal to caudo-distal is evident. d) At 84 days post ORIF and 2 days post dorsal plate removal, reduction of the fracture was attempted with lag screws (*), but the gap between the fracture ends widened and thus the horse was destroyed.

Peri-prosthetic fracture is a known complication even when plates are still in place and the bone sustains another traumatic injury. The ends of bone-plate constructs are particularly susceptible to fracture because of the abrupt transition from high to low bone rigidity.[5]

It is recommended that, whenever possible, removal of implants be done in the standing sedated horse using a minimally-invasive technique, for example by loosening screws through single stab incisions over the screw head and extracting the plate proximally or distally.[29] As difficult as it may be for the operating team, this method eliminates a potentially disastrous recovery from general anesthesia. A double-plating technique was chosen for fixation of many long bone fractures. When removing paired implants in weight-bearing long bones, a two-stage approach is recommended to allow the bone to gradually strengthen and regain normal function.[2,29] However, even when these precautions are addressed, complications may occur, which was confirmed in the present study when refracture occurred after staggered plate removal in a standing horse. Fixation of fractured bones with two plates is no longer popular in human medicine because of the associated complications. We feel that this method can also be problematic in horses and should be used only when necessary to reduce interference with bone healing. However, the high stability required in osteosynthesis in horses, usually because of their weight, makes double plating a recommended and routinely-used technique.[2] However, it should be remembered that when two plates are used, stress shielding is greater, cortex avascularity is enhanced, there is more substrate for bacterial growth, radiographic appreciation of fracture healing is more difficult, and two interventions are needed to remove hardware. Interestingly, two plates had been used in most of the horses that had an unsuccessful outcome in the present study, and the only ulna to refracture was one that had undergone double plating. These horses were heavy and had severe fractures, which made them better candidates for double plating, but based on their outcomes, more research on double plating is needed.

Although significant conclusions cannot be drawn from 4 cases, our results show a trend of increased risk of refracture in older horses (mean age of 14.2 years versus a mean age of 10.4 years in the other horses with lameness or infection) possibly due to deceleration of bone remodeling and healing.

Timing of plate removal also has been shown to be a factor in refracture; early removal significantly increases the risk.[8,12,23,38] The mean interval from osteosynthesis to plate removal in the present study was slightly shorter in horses with refracture (8.3 months) than in all horses with clinical signs (9.0 months), but was longer than in horses with infection (7.4 months). Although the numbers were small, there was a tendency to remove plates in horses with infection earlier than in horses with lameness. However, early plate removal was not correlated with a higher incidence of refracture in horses.

All refracture cases involved bones proximal to the carpus or tarsus, presumably because these are large bones that have long fracture lines and sustain great forces. Moreover, it is difficult to access these bones surgically because of the many soft tissue layers, which make optimal reduction, stabilization, and fixation challenging. The only horse that was not euthanized after refracture had an ulnar fracture and was the only patient in this group that did not have infection involving the plate. This horse was considered a candidate for a second osteosynthesis because the ulna is not a full weight-bearing bone and there was no infection to interfere with bone healing.

Using a hydro-pool system for recovery from general anesthesia may have prevented refracture in 2 horses. However, an increase in the risk of postoperative infection has been associated with hydro-pool systems[40]**,** and thus this recovery technique was not indicated because of existing osteomyelitis. Restricted exercise and limited load on the operated bone are necessary to prevent refracture after implant removal. Although detailed instructions were given to all owners for management during convalescence, one horse suffered a refracture while unsupervised on pasture 45 days after plate removal (Fig. 5a-e).

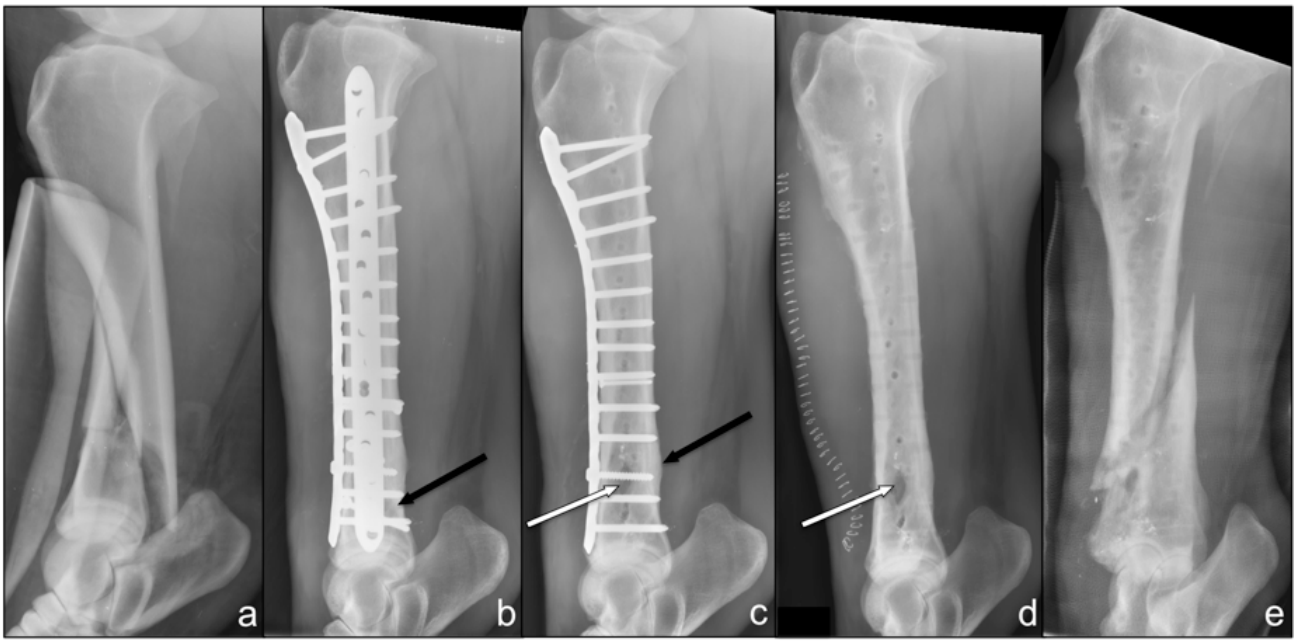


Fig 5: Radiographic views of a left tibial fracture before and at various times after osteosynthesis in a 22-year-old horse (case 14/15; 280 kg). a) Latero-medial view of an acute open comminuted diaphyseal fracture of the left tibia with moderate cranial dislocation, mild shortening, and angulation. b) Latero-medial view at 11 months after ORIF using 2 plates; the horse was evaluated for a fistula over the medial plate and mild purulent secretion. The radiograph shows advanced healing of the fracture, but superimposition of the implants limits evaluation of bone radiopacity. There is an area of ill-defined radiolucency in the mid-distal third tibial shaft and associated mild soft tissue swelling, which were thought to be due to osteomyelitis (black arrow). c) Latero-medial view at 14 months after ORIF and 3 months after removal of the lateral plate; the fistula and purulent discharge were still present. There is advanced healing of the fracture with bridging callus on the cortex (black arrow), an obvious area of well-defined radiolucency in the mid-distal third tibial shaft and mild worsening of the soft tissue swelling (white arrow) coinciding with the area of the fistula. d) Latero-medial view at 13.5 months post ORIF and 10 days after removal of the dorsal plate; advanced healing of the fracture is evident, the fracture line is no longer visible and a chronic well-defined radiolucent area (white arrow) and mild generalized smooth periosteal reaction in the area of the cranial plate are seen. e) Slightly oblique view of the same patient wearing a cast as a first aid measure, 16 months after ORIF and 45 days after dorsal plate removal; an acute refracture in the area of the original fracture is evident. This horse was euthanized.

Considering its retrospective nature, limitations of the present study include the fact that cases were very heterogeneous and some data were missing. Nevertheless, it can be concluded that infection is the most common indication for implant removal in horses and is associated with the worst outcome and most severe complications. Prevention of infection is of paramount importance and should be the focus of further research to reduce the need for plate removal as well as the occurrence of complications when removal is unavoidable. Plate removal has a good outcome in most cases and is the only choice in horses with clinical signs associated with implants. Plate removal surgery *per se* has a low complication rate and can be carried out with few concerns, even in foals. Further studies using larger patient samples are needed to substantiate these findings.

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# 7. Curriculum Vitae

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